Instability, transition and turbulence in plane
Couette flow with system rotation

P. Henrik Alfredsson & Nils Tillmark
KTH Mekanik, SE-100 44 Stockholm, SWEDEN

System rotation may drastically change the flow behaviour both for laminar and turbulent shear
flows due to the effect of the Coriolis force. For rotating plane Couette flow the Coriolis force will
either be stabilizing or destabilizing across the full channel width due to that the sign of vorticity
of the basic flow profile is the same across the channel.

Key Words: plane Couette flow, system rotation, instability, turbulence

1. Introduction
It has been known for a long time that effects due to
body forces, such as curvature (centrifugal effects) or
rotation (Coriolis effects), may have strong influence on
boundary layer development. In cases with system
rotation, if there is a component of the rotation vector
that is parallel to the wall and normal to the mean flow
direction, the Coriolis effects may lead to an unstable
"stratification" which may lead to the development of
streamwise oriented vortices. If the flow experiences
system rotation the Coriolis force may be stabilizing or
destabilizing depending on the direction of rotation. If
the mean vorticity is of the opposite sign as compared to
the system rotation vector then the flow becomes
destabilized (anticyclonic rotation), whereas the flow
becomes stabilized if they have the same sign (cyclonic
rotation) (see figure 1).

In plane Poiseuille flow the flow becomes
destabilized on one side of the channel whereas in the
other part of the channel it becomes stabilized (see e.g.
Alfredsson & Persson, 1989). For plane Couette flow on
the other hand, the Coriolis force will either be
stabilizing or destabilizing across the full channel width.

There have been a few numerical studies made
on plane Couette flow rotating around its spanwise axis.
Bech & Andersson (1996, 1997) made simulations with
destabilizing rotation and found that secondary flow in
form of streamwise oriented vortices occurs also in this
case both for weak and strong rotation. The paper by
Komminaho et al. (1996) was mainly devoted to the
non-rotating case, however they also showed that the
flow can be relaminarized by weak cyclonic rotation.

Nagata (1998) studied stationary flow
solutions which bifurcate from the two-dimensional
streamwise vortex flow in rotating Couette flow. He
showed that such a stationary solution may exist within a
rather limited Reynolds number range and that for high
Reynolds numbers these solutions would become
time-dependent.

2. Theoretical considerations
For the flow under study there are two non-dimensional
parameters of interest, namely the Reynolds number,
\(Re=U_w h/v\) and the rotation number \(Ro=2\Omega h/U_w\),
where \(2h\) is the channel width, \(2U_w\) is the velocity
difference between the walls and \(\Omega\) is the spanwise
component of the angular velocity of the system
rotation.

For plane Couette flow with spanwise system
rotation, the Coriolis force will either be stabilizing or
destabilizing across the full channel width giving rise to
spanwise periodic disturbances in the form of roll cells.
Lexius & Johnston (1976) showed that for rotating plane
Couette flow the critical Reynolds number for such
disturbances is given by the following expression

\[
Re_c = 10.3 [Ro(1-Ro)]^{1/2}
\]

which gives the lowest \(Re_c\) as 20.6 for a rotation number
\(Ro=0.5\). The corresponding critical spanwise wave
number is \(\beta_c=1.56\) i.e. the spanwise size of each roll cell
is equal to the channel height (2h). For \(Ro<0\) and \(Ro>1\)
it is seen that the flow is stable.

3. Experimental set-up
The present Couette flow apparatus has been used in a
number of reported experiments and its basic technical
details are found in Tillmark & Alfredsson (1992), which
justifies that only a brief description will be given here.

The Couette apparatus itself consists of two
open tanks connected by a 1500 mm long open plane
channel with vertical parallel glass walls. The channel
has a rectangular cross section, its vertical extent is 400
mm and the distance between the walls is adjustable
between 10 mm and 70 mm. The flow in the channel is
set up by a transparent polyester plastic belt (360 mm
wide) which runs along the facing inner glass surfaces of
the channel. Vertical cylinders in each tank drives and
steers the belt loop. A feedback controlled DC-motor
drives one of the large cylinders and a tacho-generator on
the other large cylinder, which is driven by the belt itself,
monitors the band speed. The working fluid is water and
for flow visualization it is seeded with light reflecting

This document is provided by JAXA.
platelets (Merek, Iridion 120).

4. Some experimental results
We show here only a few examples on flow phenomena that occur in the rotating plane Couette flow. Fig. 2 shows the Re-Ro-plane with the neutral stability curve and data points which verify the linear theory. We also depict various other types instability modes that occur in the flow field.

Fig. 3 shows a flow visualization photograph at low Re (~100) and Ro=0.05 where the roll cells have started to become wavy. An interesting aspect of this flow is that the roll cells eventually break down where after they reappear and the cycle repeats itself. These flow structures resemble the solutions found by Nagata (1998).

Rotating Couette flow show a number of interesting instabilities and other flow phenomena which makes it an interesting flow for both theory and experiments. Future experimental work should aim at detailed velocity measurements of the flow filed. For this PIV would be the best technique.

References


Figure 1. Superposition of rotation on a shear flow a) Stabilizing (cylonic) rotation, b) Destabilizing (anti-cylonic) rotation.

Figure 2. Stability diagram of rotating plane Couette flow.

Figure 3. Roll-cells with large-scale wavy pattern. Vertical dimension of roll cells is approximately 2h. Re=100, Ro=0.05.